Video Article

Measurement Of Neuromagnetic Brain Function In Pre-school Children With Custom Sized MEG

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Abstract

Magnetoencephalography is a technique that detects magnetic fields associated with cortical activity [1]. The electrophysiological activity of the brain generates electric fields - that can be recorded using electroencephalography (EEG)- and their concomitant magnetic fields - detected by MEG. MEG signals are detected by specialized sensors known as superconducting quantum interference devices (SQUIDs). Superconducting sensors require cooling with liquid helium at -270 °C. They are contained inside a vacumm-insulated helmet called a dewar, which is filled with liquid. SQUIDS are placed in fixed positions inside the helmet dewar in the helium coolant, and a subject's head is placed inside the helmet dewar for MEG measurements. The helmet dewar must be sized to satisfy opposing constraints. Clearly, it must be large enough to fit most or all of the heads in the population that will be studied. However, the helmet must also be small enough to keep most of the SQUID sensors within range of the tiny cerebral fields that they are to measure. Conventional whole-head MEG systems are designed to accommodate more than 90% of adult heads. However adult systems are not well suited for measuring brain function in pre-school chidren whose heads have a radius several cm smaller than adults. The KIT-Macquarie Brain Research Laboratory at Macquarie University uses a MEG system custom sized to fit the heads of pre-school children. This child system has 64 first-order axial gradiometers with a 50 mm baseline[2] and is contained inside a magnetically-shielded room (MSR) together with a conventional adult-sized MEG system [3,4]. There are three main advantages of the customized helmet dewar for studying children. First, the smaller radius of the sensor configuration brings the SQUID sensors into range of the neuromagnetic signals of children's heads. Second, the smaller helmet allows full insertion of a child's head into the dewar. Full insertion is prevented in adult dewar helmets because of the smaller crown to shoulder distance in children. These two factors are fundamental in recording brain activity using MEG because neuromagnetic signals attenuate rapidly with distance. Third, the customized child helmet aids in the symmetric positioning of the head and limits the freedom of movement of the child's head within the dewar. When used with a protocol that aligns the requirements of data collection with the motivational and behavioral capacities of children, these features significantly facilitate setup, positioning, and measurement of MEG signals.

Protocol

These guidelines describe equipment and procedures for measuring cognitive brain function in preschoolers using magnetoencephalography (MEG). First, we discuss general guidelines and issues that must be considered when carrying experimental tests of cognitive function in children. Second, we describe a protocol developed to align the requirements of MEG data collection with the motivational and behavioral capacities of four-year-old children.

1. General considerations for studying young children with MEG

MEG researchers face a number of unique challenges when working with awake healthy children. First, a stark and functional laboratory environment is likely to intimidate or frighten young children. Second, the basic requirements of an experimental MEG study include restriction of movement and actively attending to a task for an extended period, conditions that many adults find tedious and uncomfortable. When studying children it becomes imperative to adapt the experimental procedures to the capacities and limitations of the children. In this section, we describe the initial steps involved in preparing the subject to participate in a data acquisition session.

1.1 Familiarization/Training Session: For pre-school children a familiarization/training session is scheduled prior to the actual data acquisition session. This session allows the child to become familiar with the environment and the researchers at their own pace. We introduce the child and the parent to the researchers and familiarize them with the lab surroundings and routines. By the end of the introductory session the parent and child understand all the steps involved in participating and understand what they should expect during data recording. If during the first visit, a child appears shy or anxious, we have a period of playtime until they feel more comfortable. Then, we proceed with the introduction of all the steps.

1.2 Explaining the environment: To explain the MEG environment to the child, we employ a theme that provides a child-friendly justification for the surroundings. For instance, the MEG system is a spaceship waiting to take the children on a space adventure where some unfamiliar events may occur. The laboratory has also been decorated with wall stickers and toys (Fig. 1), and it has a dedicated playroom. When talking to the child, we use language that children can easily understand such as 'freezing' instead of 'minimizing movement', and 'astronaut helmet' instead of 'marker-coil cap'.

1.3 Explaining the procedures to the child and to the parents: We show the child and the parent the steps that are taken before the child goes inside the magnetically shielded room (MSR). One of the first steps is to fit a five marker-coil cap on the subject's head; these coils indicate the position of the subject's head inside the MEG helmet. With the child's help, we digitize the head shape of a puppet, and then we invite the child and the parent to accompany the puppet to the MSR/spaceship. Once inside the MSR, we place the puppet's head inside the helmet to watch a movie. We then ask the child if they want to watch the movie with the puppet. If the child is comfortable and relaxed and their parent is satisfied with our protocols, we invite them to play a game inside the spaceship the next time they visit our lab.

1.4 Workbooks: We have workbooks based on the space adventure theme that shows the steps children will take during the testing session. Children are given these worksbooks to take home and work through them with their parents in preparation for the next visit. The aim of the workbooks is to emphasize the importance of the three major requirements for testing: a) the avoidance of any ferrous material inside the MSR, b) the placement of marker coil cap to ensure accurate data co-registration and c) and the importance of remaining still during digitization and data acquisition.

2. A protocol for measuring MEG signals from pre-school aged children

2.1 Equipment used during data acquisition and experimental task

Marker-coil cap: in order to align MEG data with the subject's structural information (e.g. MRI or digitized head shape), a set of five coils are placed in a swimming cap that the child wears inside the MEG helmet. These coils act as reference points and their positions are compared before and after the task to measure how much the subject's head has moved during acquisition.

Digitizer: Prior to data acquisition, the position of five marker coils and the head shape of the subject is digitized using a Polhemus Fastrak® digitizer (Colchester, VT). The digitizer consists of a pen digitizer, three receivers, a transmitter and a motion tracking unit. This process measures the location of the coils. Later these locations are matched against the location information obtained by MEG to align the acquired magnetic data and head shape.

Child MEG system: Data acquisition is done using a whole-head child MEG system (KIT, Kanazawa, Japan) [2]. Data is acquired continuously at a sample rate of 1000Hz, with an online band pass filter between 0.03 Hz and 200Hz. Marker coil positions are obtained before and after recordings to measure head movement. Data are rejected if head movement is greater than 5mm.

MEG system peripherals: Experimental stimuli are controlled with a PC using Presentation® (Neurobehavioral Systems, Albany, CA). Visual inputs are delivered by a projector that sits outside the MSR and is reflected onto the MSR screen. Auditory stimuli are delivered by Etymotic Research Model ER-30 insert earphones fitted with baby-sized foam earpieces (Etymotic Research Inc., Elk Grove Village, IL). The child is constantly monitored by closed circuit camera and the experimenter communicates with the child through a microphone.

2.2 Data acquisition: Data recording sessions involve the following stages:

Stage I: Prior to child's arrival

It is important to have all computers, software and equipment ready to start the experiment as soon as the child arrives. As a general recommendation, two experienced researchers should be present while the child and parent are in the laboratory. Clear communications between researcher, parent and child are crucial for the success of the experiment.

Stage II: After the child arrives

1. Consent forms are signed and the experimenters check if the parents have questions.
2. The experimenter checks if the child remembers all the steps introduced during the first meeting or in the booklets and reintroduces any that are not remembered. The importance of freezing or minimizing movement during digitization and data acquisition is emphasized. This can be demonstrated using a puppet.
3. Then, the experimenter checks if the child is carrying any ferrous material (clothing with glitter patches, jewelry, toys forgotten inside pockets, hair pins, etc.). If they carry a piece of clothing that contains ferrous material, we provide them with MEG safe clothing. If the parent wishes to accompany the child during the experiment, we ensure that they also remove their ferrous material.

Stage III: Getting the child ready to perform the task inside the MSR

1. The experimenter fits the cap that holds the 5 marker coils.
2. The experimenter digitizes the location of the marker coils and the child's head shape. In order to maintain heads in a fixed position, we use a neck brace which has been fitted with three receivers. It is important to reinforce the idea of minimizing movement or 'freezing' regularly to obtain a good head shape. The child may be rewarded with a sticker for doing a good job at 'freezing'.
3. The child is invited to enter the MSR. Earphones are inserted and the child is positioned in the MEG dewar helmet in a supine position.
4. Once the child is lying down comfortably with their heads inside the MEG helmet, the marker coils are connected to their power unit and the MSR door is closed. One experimenter remains (and also a parent, if desired) in the room during the entire session.
5. For entertainment during setup and between data collection blocks, a movie or cartoon can be projected onto the MSR back-projection screen.

Stage IV: Running the experiment

1. Once the MSR door is closed, SQUIDs are engaged and data acquisition starts.
2. As the child watches a movie, a coregistration pre-test is conducted to make sure that MEG signals can be coregistered to the digitized head shape. This pretest consists of matching the position of the marker coils obtained during digitization with the position shown by the MEG system.
3. Once the first test shows that the child's head is correctly positioned inside the helmet, the researcher can start the experiment: (a) the movie is muted; (b) the researcher asks the child if they are ready to "play the game"; (c) once the game starts, the experimenter regularly provides the child with feedback. For example, a child may be asked to listen to a series of sentences, and to repeat a target word such as 'cheese', as soon as they hear it. These target words are embedded in a subset of catch trials that probe continued attentiveness to the task but are not included in the final analyses.
4. Once the task is completed, another marker coil measurement is performed to monitor head position and movement.
5. Once the SQUIDs are disengaged, the MSR door is opened and the child is invited to a playroom where they can choose a prize for their good work.

3. Representative results

A representative study in our laboratory used this protocol to study the development of logic in child language. Twenty-six children aged 3-4 years (mean age 4 years and 5 months) participated in at least one acquisition session. Seventeen of those children returned for a second testing

session and five came for a third testing session. Average head movement was less than 3.7 mm (s.d. 3.1 mm), well within the 5mm threshold. Movements greater than 5mm occurred in 4.5% of the sessions, with variation ranging from 5.5 mm to 15 mm (Mean= 8.6mm, s.d.= 2.5 mm).

Figure 1. The MSR and MEG helmet have been decorated with stickers and soft toys.
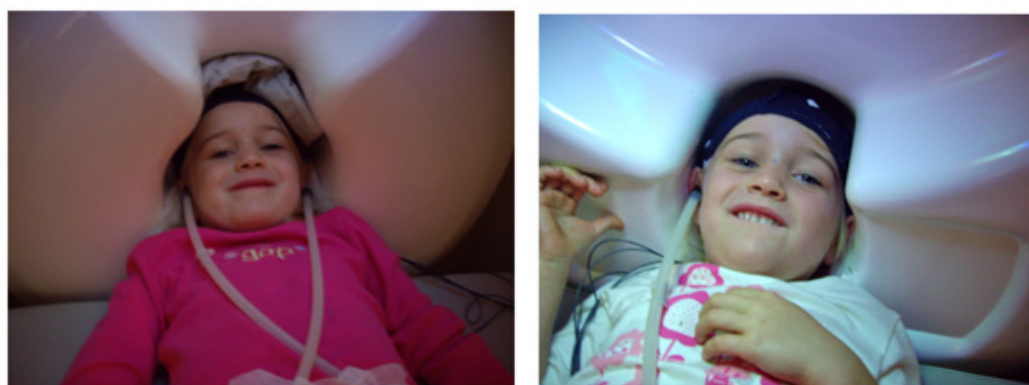

Figure 2. Four year-old girl in adult-sized MEG (left). Note the padding at the top of her head to minimize movement and the distance between head and helmet. Right picture shows same girl in the child MEG.

Discussion

This protocol is designed to facilitate measurements of cognitive brain function in healthy and awake 4 year-old children. We use a custom-sized MEG system designed to fit the heads of pre-school aged children. With this system, a child-friendly laboratory environment, and a protocol adapted to the capabilities and motivations of children, we are able to measure cognitive brain function in an age range for which there is presently very little data.

The KIT-Macquarie system is the first whole-head system custom sized for use with pre-school aged children. There are three main advantages of the customized helmet dewar for studying children. First, the smaller radius of the sensor configuration brings the SQUID sensors into range of the neuromagnetic signals of children s heads. Second, the smaller helmet allows full insertion of a child's head into the dewar. Full insertion is prevented in adult dewar helmets because of the smaller crown to shoulder distance in children (see Fig. 2). These two factors are fundamental in recording brain activity using MEG because neuromagnetic signals attenuate rapidly with distance. Third, the customized child helmet aids in the symmetric positioning of the head and limits the freedom of movement of the child's head within the dewar. These features significantly facilitate setup, positioning, and measurement of MEG signals from children.

The advent of custom sized child MEG system is an important advance for cognitive neuroscience. Alternative functional neuroimaging techniques that employ radiopharmaceuticals or strong magnetic fields may not be suitable for routine use with young children. Since MEG is an entirely passive measurement technique there is no conceivable risk to developing tissues. There is currently very little MEG data from healthy preschool aged children, because conventional adult MEG systems are not well-suited to used with children. Child MEG systems will allow us to study brain function at at ages where a dramatic structuring of brain activity is occurring, providing new insights into normal and pathological development of cognitive function.

Acknowledgements

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